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PERFORMANCE OF AN ALUMINUM OXIDE HYGROMETER ON THE NASA CV 990 AIRCRAFT METEOROLOGICAL OBSERVATORY

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ABSTRACT

An aluminum oxide hygrometer has been flown on the NASA Convair 990 aircraft on several meteorological expeditions, including BOMEX and the June 1970 flights over the Arctic Ocean, the continental United States, and the Gulf of Mexico. Water vapor data are available for most of these flights. A standard aluminum oxide probe was mounted in a specially designed air sampler. A control unit was designed such that the hygrometer system would be compatible with the flight environmental computer flown on board the 1970 expedition. Comparisons were made with other aircraft measurements yielding water vapor data and with humidity data from radiosondes, when available. These comparisons substantiate the validity of the suggested corrections to radiosonde data obtained during BOMEX. These flights have also demonstrated the negligible temperature dependence of the hygrometer data and the rapid time response of the configuration flown in a jet aircraft, which yield useful water vapor data in the range from +15C to -60C.

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1. INTRODUCTION

Water vapor plays an important role in the ultimate disposition of energy in the atmosphere. Calculations on the radiation balance of the atmosphere are based on measurements by radiosondes and a few high-flying balloons and on assumed vertical and horizontal distributions of water vapor. The NASA Convair 990 jet aircraft provided a unique opportunity to measure the water vapor distribution over a wide range of meteorological conditions, including the altitude range from the ground to 40,000 ft and from the Arctic Ocean to the Gulf of Mexico. The primary objective of these experiments was to evaluate the aluminum oxide hygrometer (Chleck, 1966) in regard to sensitivity, time response, and temperature dependence for its potential application to water vapor measurements in the stratosphere and lower mesosphere. It was also flown in support of other aircraft instrumentation requiring ambient water vapor data. Dew-frost point temperatures and mass density data taken during the June 1970

expedition (10 flights) are available, * whereas data taken during the Barbados Oceanographic and Meteorological Expedition (BOMEX) are on paper tape and are available only upon request from the authors of this paper.

2. INSTRUMENTATION

The aluminum oxide probe and calibration procedures have been described in detail by Goodman and Chleck (1969). The probe, depicted in Fig. 1, consists of an anodized aluminum foil strip 10 mm × 5 mm × 0.1 mm in size. A thin coating of gold is vacuum deposited over this strip, yielding an aluminum oxide capacitor. The gold layer is porous enough that water vapor can diffuse in and out of the aluminum oxide. Changes in the ambient water vapor pressure result in corresponding changes in the electrical impedance of the probe. Each probe has an associated calibration curve.

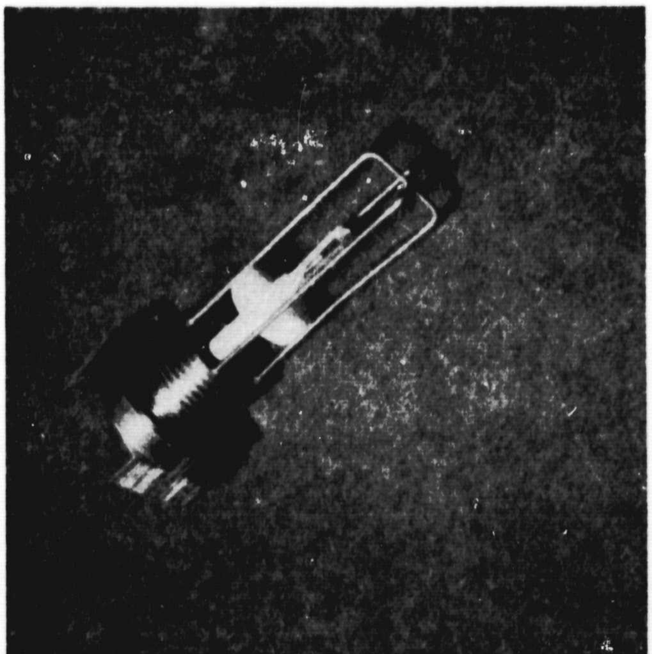

Fig. 1 Aluminum Oxide Hygrometer Element in Pressure Seal Mount.

*"Time-Environment-Position Data to Support CV 990 Experiment Data," Bendix Field Engineering Corporation, Columbia, Maryland, Contract NAS 5-11720, Goddard Space Flight Center, Greenbelt, Maryland, October, 1970.

The output of the probe is fed to the electronics and acquired by the CV 990 airborne data acquisition system, which utilizes a Hewlett-Packard 2116B computer as a real-time central processor. This system accounts for range switching in the hygrometer electronics and acquires the housing temperature. The housing thermistor monitors the air temperature in the vicinity of the hygrometer probe. The air sampling assembly, depicted in Fig. 2, is mounted in the

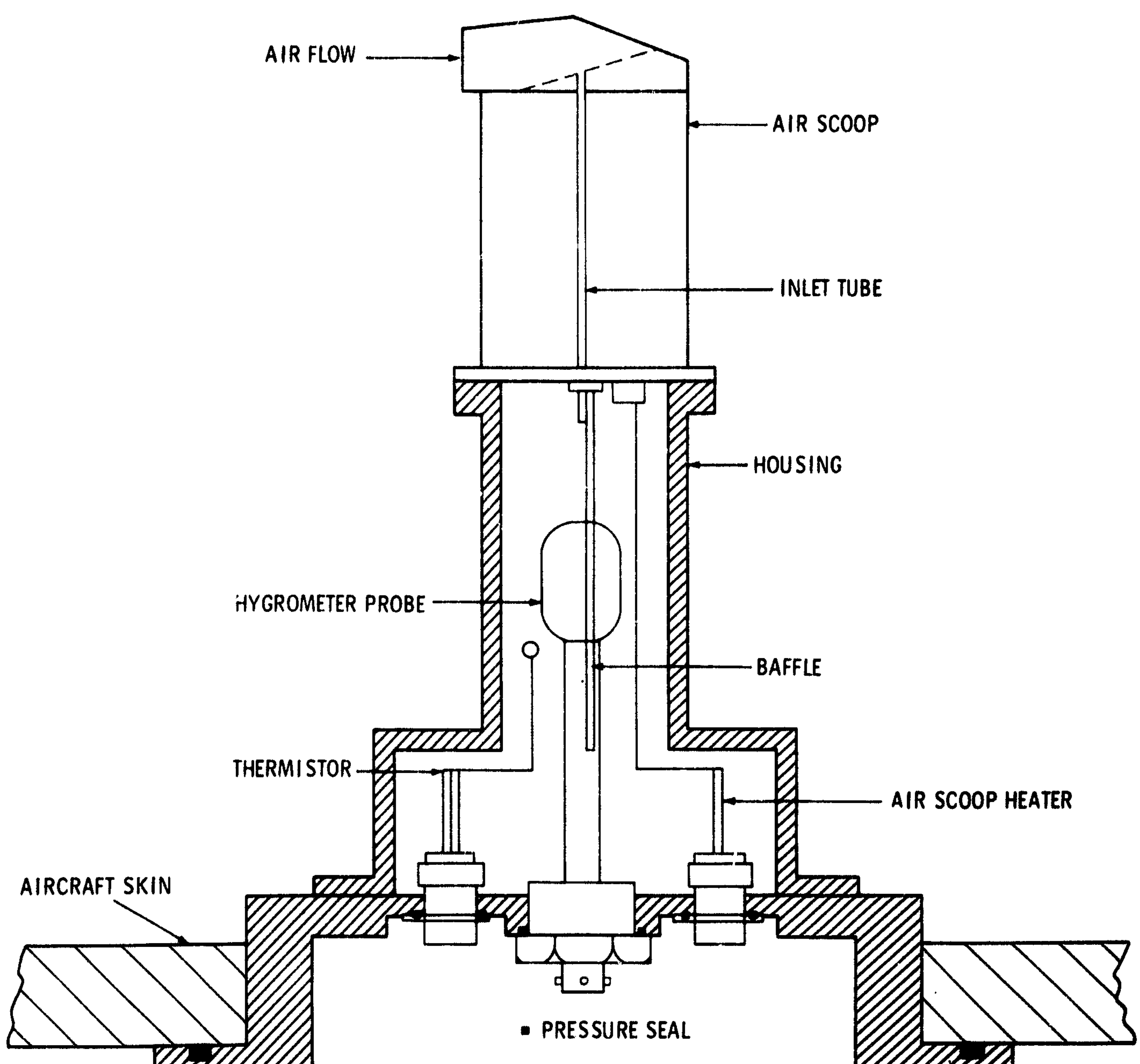

Fig. 2 Housing and Air Sampling Assembly.

forward section of the aircraft to minimize contamination from the aircraft. An air scoop protrudes above the boundary layer of the aircraft to ensure that the ambient atmosphere is sampled. The air scoop and housing are fabricated entirely of stainless steel.

3. INTERCOMPARISON WITH RADIOSONDES

The participation of the NASA CV 990 in BOMEX provided the opportunity for practically simultaneous observations of humidity with the aircraft hygrometer and with radiosondes. Vertical profiles of water vapor data can be obtained during an aircraft descent or ascent; however, because of the potential contamination problem, only descent data are used for the comparisons. Ascent and descent data will be discussed below. Morrissey and Brousaides (1970) have shown that errors exist in radiosonde humidity data due to non-steady-state temperature conditions between the humidity element and the ambient atmosphere. A correction factor was derived for various ambient pressures for a specific series of measurements and, therefore, is not necessarily applicable to all radiosonde data.

Figure 3 compares water vapor data obtained via the aircraft during a descent near the ship Discoverer on 18 July 1969. The ship was located at 13°N. 54°W., and a radiosonde was launched from the ship at 1510 GMT. The aircraft began its descent from 33,000 ft above 12°N. 54°W. at 1510 GMT and was 7000 ft above 13°N. 55°W. at 1550 GMT. It is evident that there is good agreement between the corrected humidity data from the radiosonde and the aircraft data above 18,000 ft. The differences between the data below this altitude can only

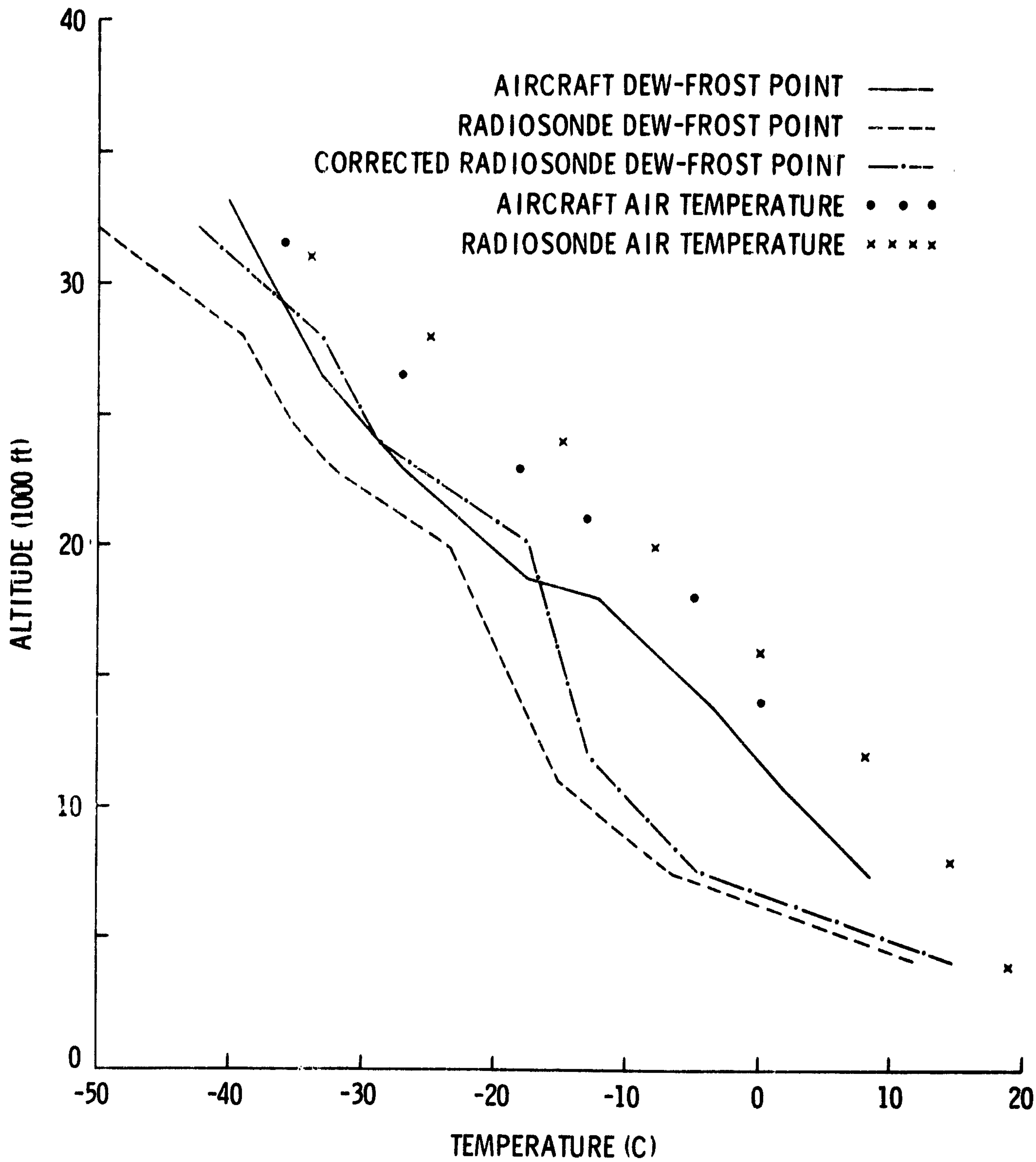

Fig. 3 Intercomparison of Water Vapor Profiles from Aircraft and Radiosonde during BOMEX.

be attributed to local meteorological conditions in the vicinity of the respective measurements. The radiosonde data clearly indicate a dry layer, whereas the aircraft in this altitude range was in clouds with some precipitation. This

condition is demonstrated by the dew-frost point temperatures in this vicinity, which were close to saturation. Other examples showing good agreement with corrected radiosonde data were obtained during BOMEX.

Figure 4 is a comparison of data from the aluminum oxide hygrometer on the June 1970 series of flights and from a radiosonde flown from ship Papa in the Northern Pacific. The ship was located at 50°N. 145°W., and the balloon was launched at 2300 GMT. The aircraft began its descent above 51°N. 145°W. at 2240 GMT and was 5000 ft above 51°N. 146°W. at 2245 GMT. In this case agreement is good with no correction to the radiosonde. Teweles (1970) suggests that the relative size of the errors experienced by the radiosonde humidity data can result from a number of factors, although they are primarily due to the amount of incident solar radiation. These errors can be induced by operational circumstances, such as cloudiness, swinging of the sonde, and preparation of the sonde for flight, which vary from one flight to the next. Therefore, it is not unreasonable to say that the radiosonde flown from ship Papa may need a smaller correction than those flown during BOMEX, or none at all. Figure 4 also compares the ambient temperatures obtained by the aircraft and by the radiosonde.

4. WATER VAPOR AMOUNTS DURING A FRONTAL ENCOUNTER

The following is an example of the detailed measurements of water vapor that can be obtained with the airborne hygrometer. On 12 June 1970, the CV 990 encountered a frontal system in the North Pacific. The surface weather chart for 0000 GMT 13 June 1970 locates a cold front at 142°W. running almost due north at 50°N. The front and the horizontal and vertical flight paths of the

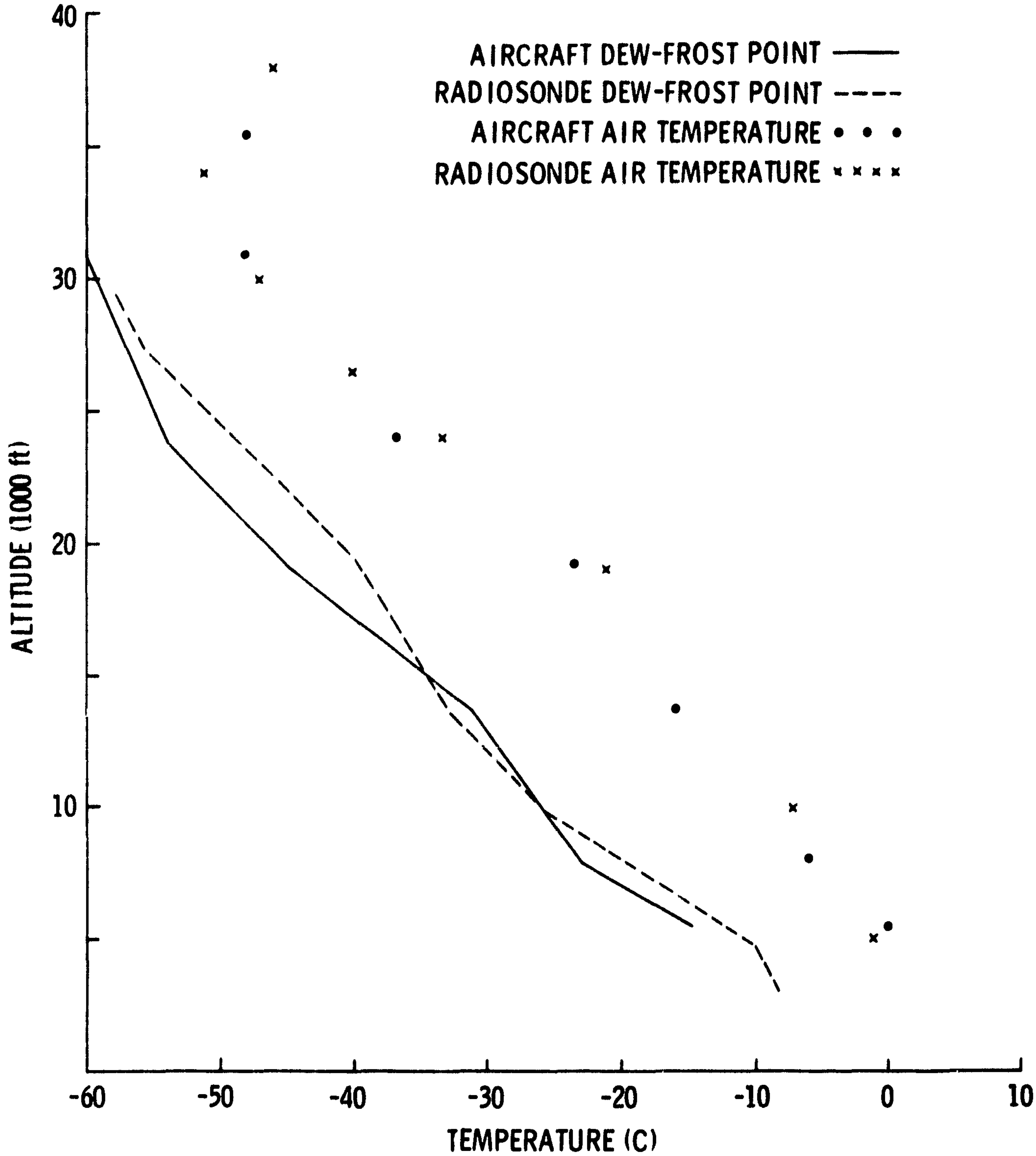

Fig. 4 Intercomparison of Water Vapor Profiles from Aircraft and Radiosonde in the North Pacific in June 1970.

aircraft are shown in Fig. 5 as functions of time. Water vapor data are plotted as a function of time in Fig. 6. Data from Figs. 5 and 6 for points equidistant from the front are combined to yield water vapor densities as a function of

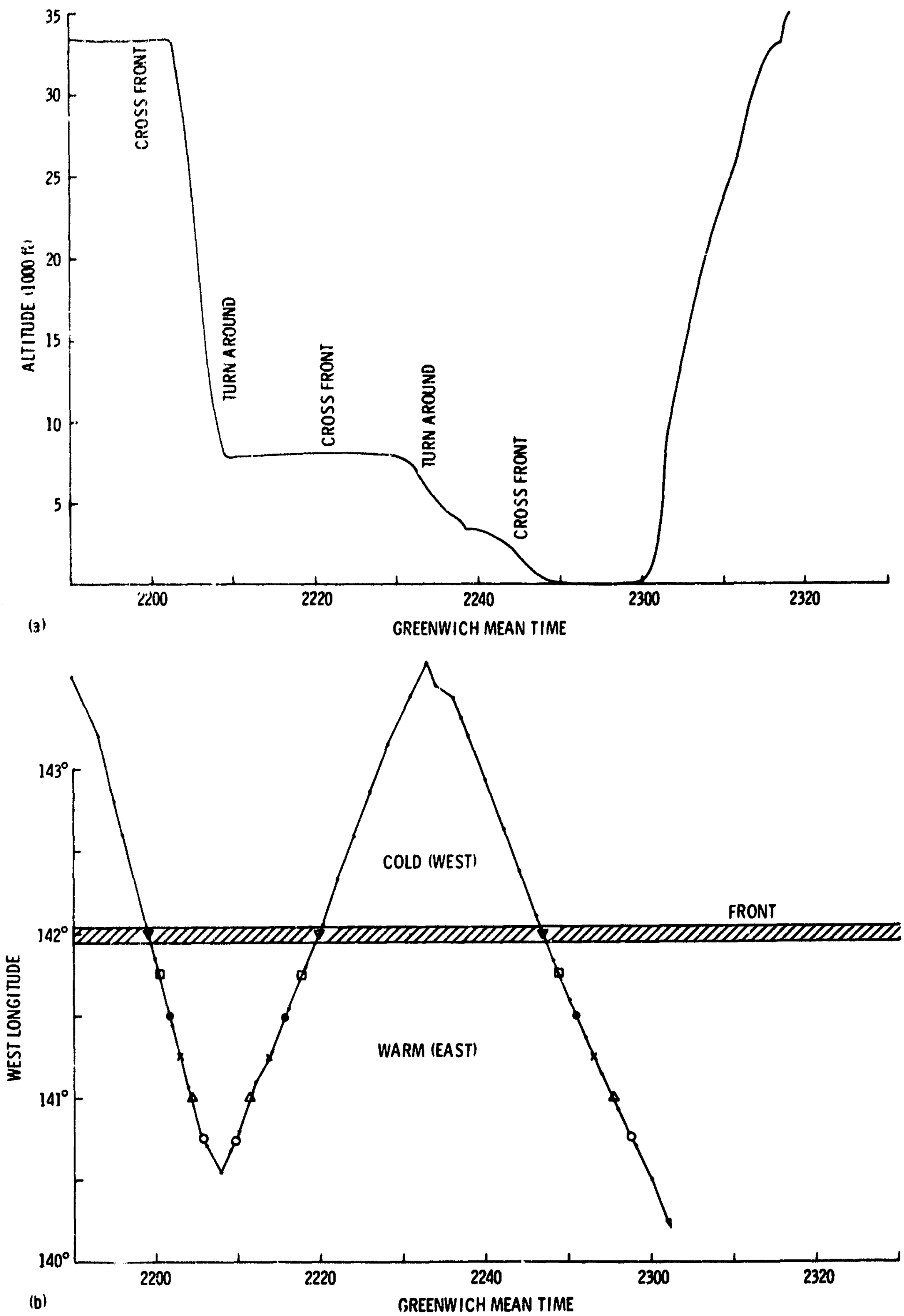

Fig. 5 Aircraft Flight Path as (a) a Function of Time and (b) Relative to a Weather Front in the North Pacific.

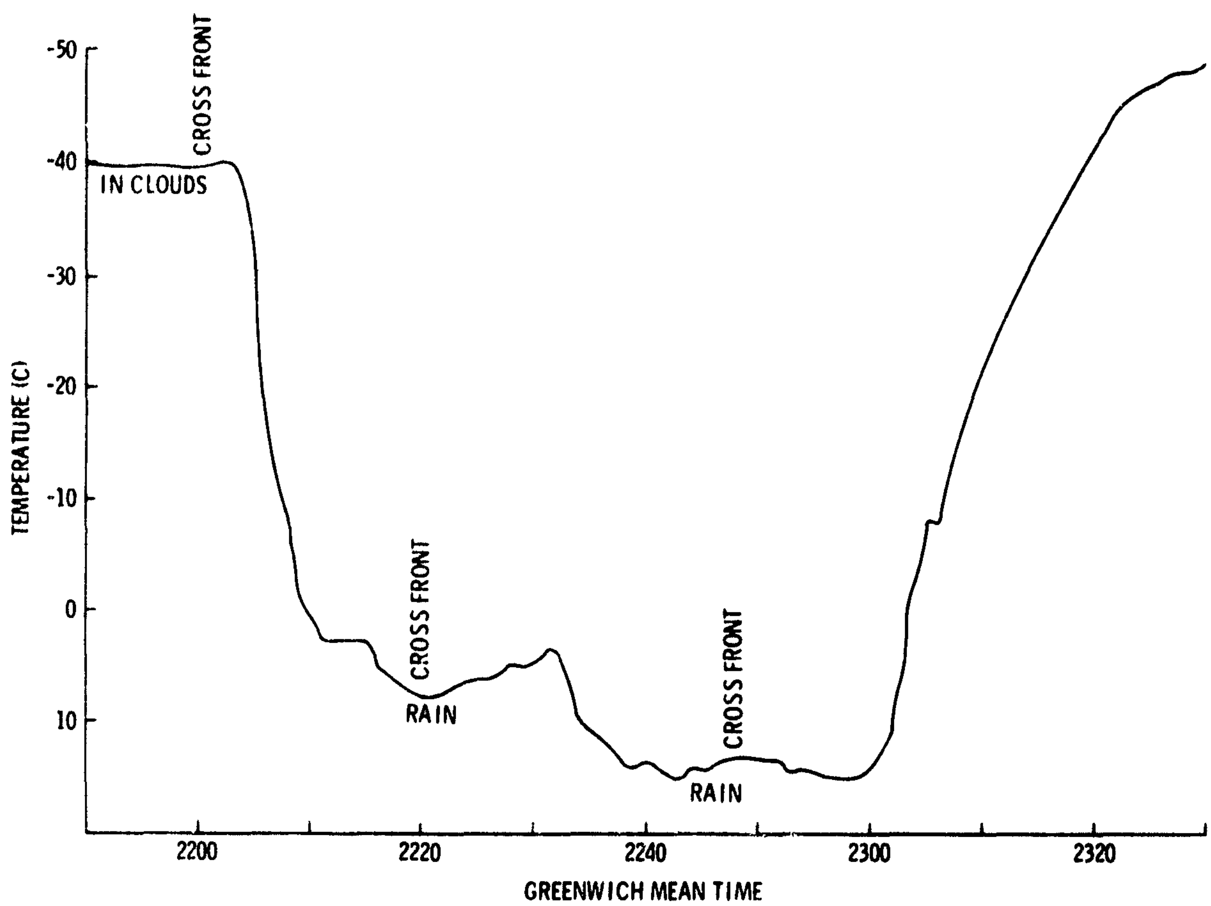

Fig. 6 Dew-Frost Point as a Function of Time Relative to a Weather Front in the North Pacific.

altitude in Fig. 7. Also shown are the integrated water vapor amounts, which range from 4.6 g/cm^2 over the front to 3.3 g/cm^2 east of the frontal zone. This drying is also evident at the 8000-ft level shown in Fig. 6. An aircraft-mounted, downward-looking microwave radiometer operating at 22.2 GHz measured total water vapor up to the front from 33,000 ft and indicated a maximum total water vapor of about 4 g/cm^3 at 141° 50'W.* An instrument of this type and the interpretation of its data have been discussed by Staelin (1969).

5. TIME RESPONSE AND TEMPERATURE DEPENDENCY

Laboratory experiments with the aluminum oxide probe give strong evidence of negligible temperature sensitivity and rapid time response, approximately

*D. Staelin, private communication.

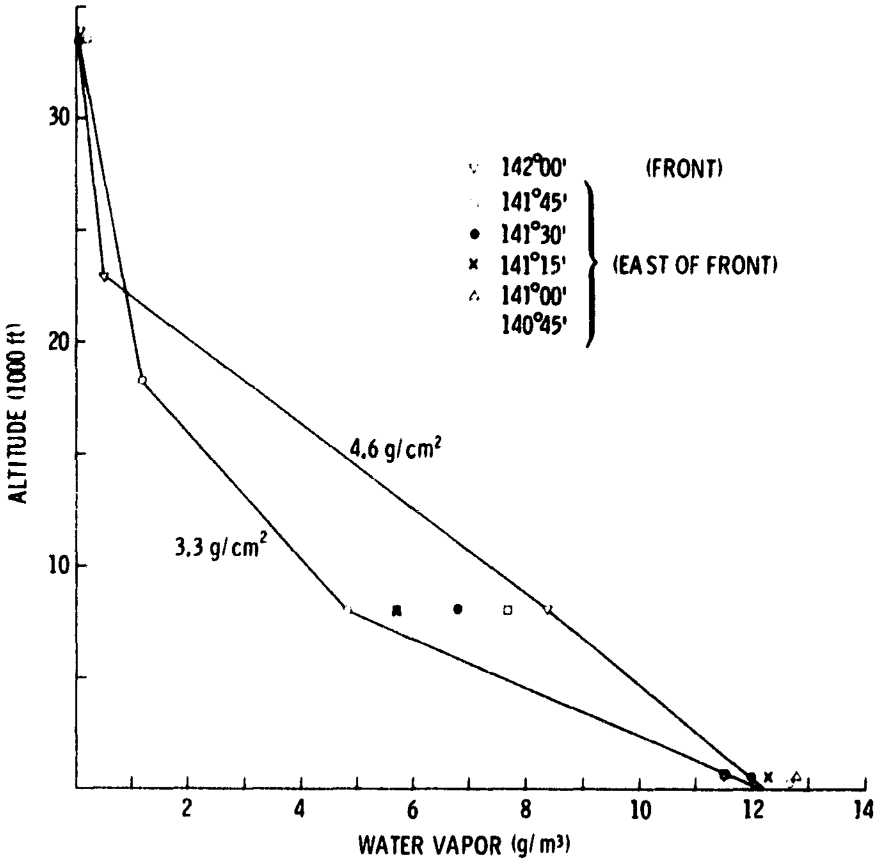

Fig. 7 Water Vapor Profiles and Total Water Vapor in the Vicinity of a Weather Front in the North Pacific.

one second over most of the range. Measurements to verify these characteristics absolutely are extremely difficult to perform, especially in the case of water vapor sensing, because of the difficulty in determining the condition and response of the laboratory environment. Measurements performed in the jet aircraft do not definitely answer these questions; however, they do give more insight into the performance of the hygrometer. Although the results indicated in Figs. 3, 4, and 7 demonstrate that the aluminum oxide hygrometer does indeed measure ambient conditions when compared with other experimental techniques, it would be desirable to show internal consistence in its performance. Figure 8 presents examples of data taken during the flight on 19 June 1970 over the Mojave Desert in southern California. This figure indicates aircraft altitude, ambient

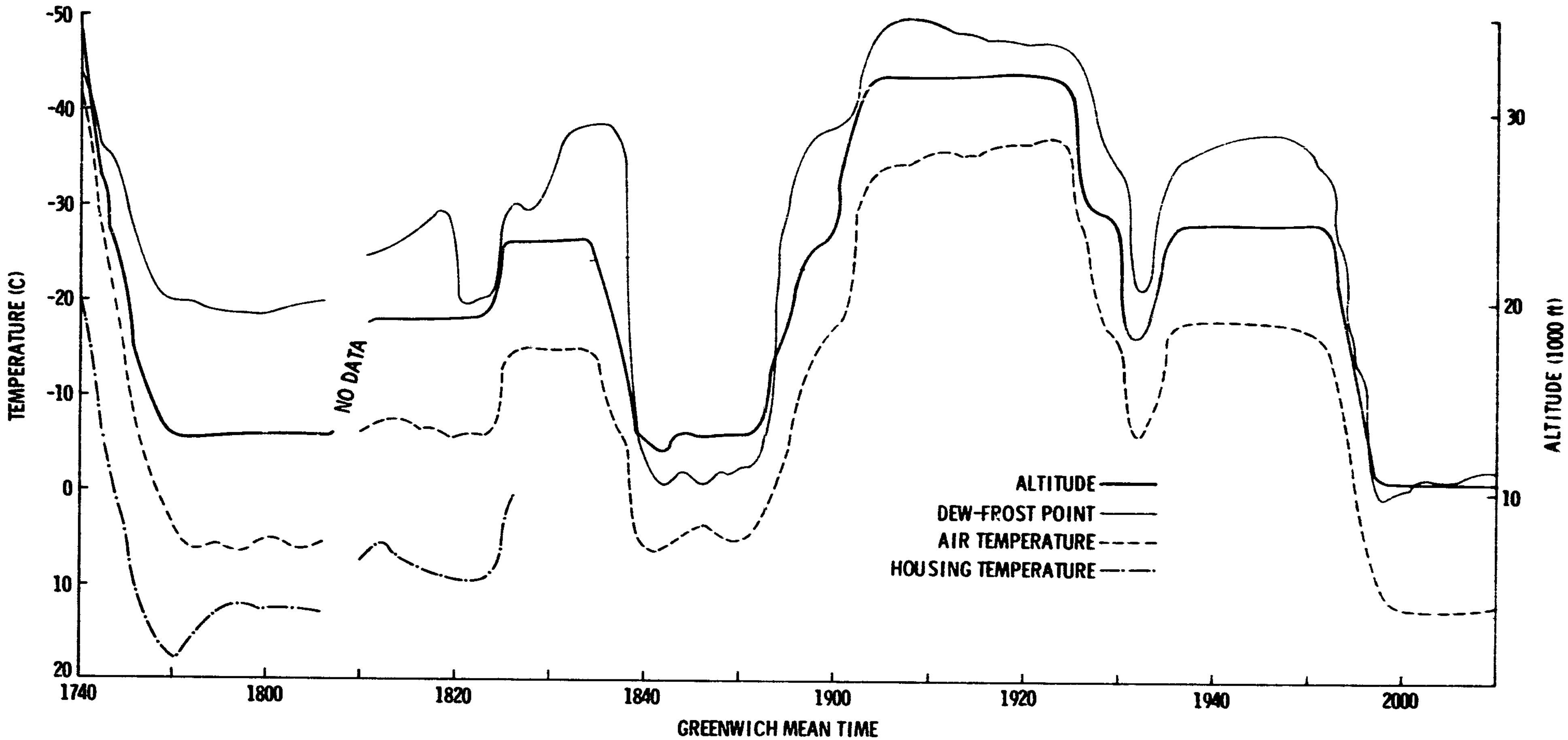

Fig. 8 Altitude, Dew-Frost Point, Ambient Air Temperature, and Ho… ng Temperature as Functions of Time During a Flight from Houston, Texas to Moffett Field, California, June 1970.

temperature, dew-frost point, and, during the period from 1740 GMT to 1825 GMT, hygrometer housing temperature. The housing temperatures and dew-frost points in the intervals from 1750 GMT to 1755 GMT and from 1810 GMT to 1817 GMT demonstrate the lack of temperature sensitivity; in fact, the latter time interval indicates a decreasing water vapor concentration with an increase in temperature in the vicinity of the probe. The converse has been considered a likely source of error in measured dew-frost point temperatures. Housing temperature is determined mainly by the ambient temperature and the aircraft skin temperature. This equilibrium temperature can be changed by variations in the power applied to the air scoop heater and in direct or reflected solar radiation from clouds.

Most of the data taken during the interval plotted on Fig. 8 indicate relatively dry conditions (relative humidity from 10% to 20%). The data demonstrate that the responses are about equal in the upleg and the downleg portions of the flight. Aircraft altitude changes indicate that dew-frost point variations can be measured within ±0.5 C/sec in the range from 0C to -50C. The air sampler has a volumetric flow of approximately 1 ft^3/min and varies approximately ±20% with air speed and altitude. Thus, the hygrometer housing exchanges air approximately every 10 sec. There have been exceptions to this rapid recovery, so that during certain portions of the flight the humidity data were in error. For example, extended flights (several minutes) near sea level at high humidities have caused a lag in the data during the ascent portion of the flight. Also, rapid response is inhibited if icing of the probe or any portion of

the housing occurs after penetration of a cloud or during rapid ascent. This rarely occurs, however, because of the heating element in the air scoop.

6. CONCLUDING REMARKS

The aluminum oxide hygrometer mounted in the configuration described above has demonstrated its unique ability to make *in-situ* airborne water vapor measurements at speeds near Mach 1 and at altitudes up to 40,000 ft. The hygrometer showed a sufficiently rapid response time to permit valid measurements during descents and ascents of approximately 5000 ft/min. Because of its sensitivity and response time, the airborne hygrometer is capable of making detailed measurements of water vapor during meteorological events such as frontal encounters.

The aluminum oxide hygrometer will be flown on future meteorological expeditions. Improvements in the probe and air sampler have been incorporated to further limit the possibility of contamination. It is expected that this device will also be suitable for aircraft measurement of water vapor in the lower stratosphere.

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